VirtoScan-on-Rails – an automated 3D imaging system for fast post-mortem whole-body surface documentation at autopsy tables

Kottner, Sören ; Schaerli, Sarah ; Fürst, Martin ; Ptacek, Wolfgang ; Thali, Michael ; Gascho, Dominic

Abstract: Two-dimensional photographic documentation is a substantial part of post-mortem examinations for legal investigations. Additional three-dimensional surface documentation has been shown to assist in the visualization of findings and contribute to the reconstruction of the sequence of events. However, 2D photo documentation and, especially, 3D surface documentation, are time-consuming procedures that require specially trained personnel. In this study a 3D imaging system, called VirtoScan-on-Rails, was developed to automate and facilitate 3D surface documentation for photo documentation in autopsy suites. The imaging system was built to quickly acquire photogrammetric image sets of whole bodies during different stages of external and internal examinations. VirtoScan-on-Rails was set up in the autopsy suite of the Zurich Institute of Forensic Medicine at the University of Zurich (Zurich, Switzerland). The imaging system is based on a movable frame that carries a multi-camera array. Data quality and the applicability of the system were analyzed and evaluated within two test series. Up to 200 overlapping photographic images were acquired at consecutive image-capturing positions over a distance of approximately 2000 mm. The image-capturing process took 1 min and 23 s to acquire a set of 200 images for one side of the body. During test series one and two, 53 photogrammetric image sets taken from 31 forensic cases were successfully reconstructed. VirtoScan-on-Rails is an automated, fast and easy-to-use 3D imaging setup for autopsy suits. It facilitates documenting bodies during different stages of forensic examinations and allows standardizing the procedure of photo documentation.

DOI: https://doi.org/10.1007/s12024-019-00095-5

Forensic Science, Medicine and Pathology

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--Manuscript Draft--

Manuscript Number:	FSMP-D-18-00318R1
Full Title:	VirtoScan-on-Rails – an automated 3D imaging system for fast post-mortem whole-body surface documentation at autopsy tables
Article Type:	Original Article
Keywords:	3D surface scanning; Photogrammetry; Photographic documentation; Multi-camera setup; Forensic external examination; autopsy
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Funding Information:	
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Title

VirtoScan-on-Rails – an automated 3D imaging system for fast post-mortem whole-body surface documentation at autopsy tables

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Abstract

Purpose: Two-dimensional photographic documentation is a substantial part of post-mortem examinations for legal investigations. Additional three-dimensional surface documentation has been shown to assist in the visualization of findings and contribute to the reconstruction of the sequence of events. However, 2D photo documentation and, especially, 3D surface documentation are time-consuming procedures that require specially trained personnel.

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Results: Up to 200 overlapping photographic images were acquired at consecutive image-capturing positions over a distance of approximately 2000 mm. The image-capturing process took 1 min and 23 s to acquire a set of 200 images for one side of the body. During test series one and two, 53 photogrammetric image sets taken from 31 forensic cases were successfully reconstructed.

Conclusion: VirtoScan-on-Rails is an automated, fast and easy-to-use 3D imaging setup for autopsy suits. It facilitates documenting bodies during different

Keywords

3D surface scanning, Photogrammetry, Photographic documentation, Multi-camera setup, Forensic external examination, Autopsy

Acknowledgements

Firstly, the authors express their gratitude to Emma Louise Kessler, M.D., for her generous donation to the Zurich Institute of Forensic Medicine at the University of Zurich (Zurich, Switzerland). Secondly, the authors would like to thank Mrs. Verena Jaggi and Mr. Thomas Jacoby from the University of Zurich (Zurich, Switzerland) and Mrs. Astrid Winkler from the Austrian Center for Medical Innovation and Technology (ACMIT Gmbh, Wiener Neustadt, Austria) for their expert advice and assistance during planning and installation of the system. Finally, the authors would like to acknowledge the autopsy teams from the Zurich Institute of Forensic Medicine at the University of Zurich (Zurich, Switzerland), who greatly contributed to this study by arranging and preparing the forensic cases.

Title

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Key Points

1. VirtoScan-on-Rails is an automated imaging system for 3D surface documentation at autopsy tables
2. 3D surface documentation is based on a close-range photogrammetry setup
3. VirtoScan-on-Rails allows 3D whole-body surface imaging during different stages of external and internal examinations
4. Short acquisition times allow integrating 3D imaging into the routine work in autopsy suites
5. VirtoScan-on-Rails allows forensic pathologists and morgue technicians with a basic understanding of photography to perform post-mortem 3D surface documentation.

Introduction

Photographic documentation is a fundamental part of post-mortem external and internal examinations. Its purpose is to objectively document all morphological findings that are relevant to the case. Depending on the circumstances of the case, this procedure also usually includes documenting the absence of findings [1–4]. To prepare a photographic documentation that can be used in line with a legal investigation, the documentation procedure must fulfill certain requirements. Photographs that are used for the documentation must allow the unambiguous assignment of each injury to the exact location on the body [4]. In addition to that, photographic material must characterize the size and type of injuries [4]. Finally, it is of course necessary that all photographs included in the documentation be prepared in a technically correct manner and exhibit perfect image quality [1–7]. These requirements are why photo documentation usually combines photographs showing full-body overviews with detailed pictures of the findings. This procedure is typically carried out to document the body at the state of arrival, after cleaning and during the internal examination [1,2]. By doing so, it is possible to document findings such as defects and contaminations on the clothes and the body's surface as well as medical installations or other foreign materials and objects. In general, it is important that findings be recorded from various angles orthogonal to the body's surface and including a measuring scale [1–8].

Photo documentation is commonly carried out by forensic pathologists or experienced photographers from forensic institutes or the police forces. It is crucial that this task be carried out by personnel with sufficient understanding and experience in photography. In addition to the technical aspects of the documentation procedure, the image quality is one of the most important components of the photo documentation. Most commonly, photographic documentation refers to a two-dimensional (2D) documentation. In many cases, however, it can be helpful to extend this two-dimensional data [7]. With the help of photogrammetry, a set of 2D images can be used to digitally reconstruct a three-dimensional (3D) representation of the captured object or body region [9]. To create a photogrammetric dataset, a series of photographs with overlapping images taken from different angles must be prepared. This procedure is time consuming and typically requires the knowledge of experienced specialists.

In the past two decades, photogrammetric techniques have been used in various studies to illustrate their applicability in the field of forensic medicine [10–20]. 3D imaging techniques are now commonly used in general and have become beneficial tools in line with the aims of forensic investigations [21–31]. However, due to the required technical knowledge and the time-consuming process, 3D whole-body imaging during external and internal examinations does not seem to be commonly used. To make 3D imaging more applicable for autopsy suites, it is desirable to have a 3D imaging device that can quickly acquire high-quality textured 3D data from whole bodies in an automated and user-friendly manner.

This need is why this study aimed to develop and set up an automated 3D imaging solution for autopsy facilities. The imaging system was built to document external and internal examinations in a textured three-dimensional data format. This setup, henceforth referred to as “VirtoScan-on-Rails”, was based on our recent research project [32,33] and was then further developed in collaboration with blinded. To ensure that the system met the requirements, it was first tested whether the VirtoScan-on-Rails can be used to document various bodies (dressed and undressed) during external examinations and during internal examinations (e.g., during autopsy procedures or organ displays). Second, whether the system can acquire high-quality 3D data in a short amount of time to integrate the system into routine work in the autopsy suite was evaluated. Finally, whether the 3D imaging procedure can be automated and simplified so that it can be performed by morgue technicians or forensic pathologists who do not have any prior experience in 3D imaging was tested.

Methods and Material

Input specifications and place of installation

VirtoScan-on-rails was installed at the autopsy facility at the blinded. The autopsy facility at the blinded comprises two separated autopsy rooms and one morgue, including two separate maintenance rooms and one delivering hall (Fig 2.1 a). Several rooms dedicated to post-mortem imaging and analysis are adjacent to these facilities.

VirtoScan-on-rails was customized for autopsy room 1, the larger of the two autopsy suites (Fig 2.1 b). Autopsy room 1 is directly connected to autopsy room 2, the morgue and connects the autopsy facilities with the post-mortem imaging facilities. It features a ground area of approximately 9.75 m by 5.50 m and a ceiling height of 3.00 m. The entire autopsy facility at the blinded was fully refurbished in 2016 and holds state-of-the-art ventilation, cleaning and storage equipment. Additionally, autopsy room 1 comprises two autopsy tables with two dedicated computer workstations. Each autopsy table measures 3150 mm in length, 900 mm in width and offers a continuously adjustable height ranging from 750 mm to 1150 mm. Each table features a separate ventilation system with a laminar flow module, a lighting system with daylight light sources (color temperature: 4000 Kelvin) and a ceiling camera (Canon EOS 750D, Canon Inc., Tokyo, Japan) with a wide-angle lens (Canon EF-S 10-22 mm f/3.5-4.5 USM, Canon Inc., Tokyo, Japan) allowing the capture of whole-body images.

Due to the given measurements of the autopsy room and the available space for installation, it was necessary to find an appropriate storage solution for the imaging system when it is not in use. To integrate the VirtoScan-on-Rails into routine work, it was crucial to develop a fast imaging system that can be started up instantly and that quickly captures a full set of photogrammetric images over the length of approximately 2000 mm.

Hardware setup

The VirtoScan-on-Rails contains three main components: the linear motion and lifting unit, the image capturing unit and an operating unit for user inputs. The linear motion and lifting unit comprises two parallel linear guide rails that are 8.60 m long (LIL 5010, Robotunits GmbH, Dornbirn, Austria). These rails are mounted to the ceiling parallel to the table axes. Farther down, these two guideways contain timing belt systems that are connected by a torque shaft and are actuated by a synchronous servomotor (RZ37 CMP63M, SEW-EURODRIVE GmbH & Co KG, Bruchsal, Germany). The servomotor enables the base frame of the image-capturing unit to move along the linear axis. An additional rotation axis is implemented at the camera base frame of the image-capturing unit. To provide lifting capability, the rotation axis is actuated by two electric cylinders (LZ 60 P, RK Rose+Krieger GmbH, Minden, Germany). This way, the image-capturing unit provides sufficient clearance underneath to work at autopsy tables without any major restrictions.

The image-capturing unit is designed with an arched frame that carries a multi-camera array. The camera array comprises 10 Canon EOS 100D (Canon Inc., Tokyo, Japan) digital single-lens reflex cameras (DSLR). All cameras are equipped with a Canon EF lens with a fixed focal length of 50 mm (Canon EF 50 mm 1:1.8 II, Canon Inc., Tokyo, Japan).

The operating unit contains a control panel and a handheld enabling switch (ZSB 08126, EUCHNER GmbH + Co. KG, Leinfelden-Echterdingen, Germany). The control panel allows switching between programs either to park the system or to acquire images on the first or the second autopsy table. The handheld enabling switch allows the operator to start or stop the selected programs and is used as continuous confirmation of any movements by the operator as additional safety measure.

Software setup

VirtoScan-on-Rails is built to use three different software programs: VirtoScan-Firmware (VirtoscanSW V0.9, blinded), DSLR Remote Pro Multi-Camera (Version 1.9.4, Breeze Systems Limited, Camberley, United Kingdom) and Agisoft PhotoScan Professional Edition (Version 1.2.6, Agisoft LLC, St. Petersburg). The VirtoScan-Firmware controls the hardware of the image-capturing unit and the linear motion and lifting unit. This firmware evaluates user inputs provided by the operation unit to execute stored program workflows. Program workflows include parking and un-parking of the system or executing the image-capturing process. DSLR Remote Pro Multi-Camera allows the control of multiple Canon EOS DSLRs. This software enables setting and synchronizing camera settings, displaying parallel live views from multiple cameras and automatic downloading of captured images, among other features. Agisoft PhotoScan Professional Edition is used for the post-processing of the captured photogrammetric image data. The software allows the reconstruction of textured 3D models based on overlapping multi-view images. The processing workflow to compute a textured 3D model can be operated via an application programming interface (API) and can be automated with batch processing in order to minimize user intervention.

Image-capturing process

The basic image-capturing process is divided into three main sequences (Fig 2.2). In its inactive state, the image-capturing unit is stored at the back end of the autopsy suite and is locked underneath the ceiling in a horizontal parking position. The first sequence initially unlocks and rotates the image-capturing unit into a vertical position and subsequently moves it along the linear axis to the selected starting position (Fig 2.2 a). The starting positions are either at the beginning of autopsy table 1 or of autopsy table 2. During the second main sequence, the image-capturing unit is initially moved from the starting position towards the end of the autopsy table along the linear axis. This process is carried out in a step-by-step motion while the shutter release of the camera array is triggered. This process continues until the last set of images is captured. Subsequently, the image-capturing unit is moved back to the initial starting position (Fig 2.2 b). At this point, the image-capturing sequence can be repeated at the same autopsy table or switched to be carried out at the other autopsy table. During the third main sequence, the image-capturing unit is initially moved along the linear axis towards the back end of the autopsy suite. Subsequently, the image-capturing unit is raised towards the ceiling (Fig 2.2 c). As soon as the final parking position is reached, the system is locked and switches into its inactive state.

Camera settings

All DSLR cameras on the image-capturing unit were evenly distributed along the arched frame to acquire uniformly overlapping photographs across the axial section of the object to be scanned. Camera views were aligned manually with the help of the multi live view option from DSLR Remote Pro Multi-Camera. The camera focus was initially adjusted with the help of auto focus and afterwards was switched to manual mode. This option was chosen, firstly, to maintain the same focus settings throughout the image-capturing procedures and, secondly, to avoid blurry images due to misinterpretations by the auto focus. Parameters for all cameras were set up identically with the help of DSLR Remote Pro Multi-Camera. Cameras were set up to use the lowest possible ISO value (ISO 100) in combination with the largest possible depth of field (minimum aperture: f/22). The exposure time was set to 1/3 s to acquire images during full-room lighting. The white balance was adjusted to the color temperature of the daylight lighting system from the autopsy table (4000 Kelvin). An overview of the camera settings can be found in table 2.1.

System testing, evaluation and selection of forensic cases

Two sets of forensic cases within two test series were used to investigate the practicability of the VirtoScan-on-Rails. Whole-body imaging was performed during external and internal examinations on bodies where 3D imaging was considered as potentially useful for the documentation of findings and further crime scene reconstructions. The set of forensic cases comprised dressed and undressed bodies as well as bodies during autopsy procedures and organ displays. Forensic cases from external examinations were chosen to show visible defects and alterations on the body's surfaces. This category included injuries due to blunt or sharp force trauma such as pattern injuries, gunshot wounds, injuries in line with traffic accidents as well as severe burnings. Measuring scales were added to each body during the image-capturing procedures.

Data acquisition time, data quality and usability of the system were analyzed and incrementally improved throughout test series one and two. The results of both test series were visually analyzed and evaluated by an engineer with experience in 3D metrology, 3D imaging and analysis as well as forensic photography. Due to increased dust contamination, lens caps were used during the first test series to protect the camera lenses when the system was not in use. Subsequent to the completion of the first test series, results were used to adjust parameters for the image-capturing sequence and to improve the imaging setup. During the second test series, lens filters (Rodenstock HR Digital Super MC UV-Filter, Qioptiq Photonics GmbH & Co. KG, Göttingen, Germany) were added to each camera to protect the camera lenses from dust contamination and to avoid the use of lens caps. To avoid further changes of the focus settings, measures to mechanically fixate the focus rings on each camera lens have been taken. At the end of the second test series, results from both test runs were visually compared and evaluated.

Image registration and 3D reconstruction was carried out on a computer laptop (Dell Precision 7710, Dell Technologies, Round Rock, Texas, USA, 2 Intel® Core™ i7-6820HQ Quad Core 2.70GHz, Intel Corporation, Santa Clara, USA, 32 GB RAM, Nvidia Quadro M4000M GPU, NVIDIA Corporation, Santa Clara, USA, Microsoft Windows 7 Professional, 64 Bit, Service Pack 1 operating system, Microsoft Corporation, Redmond, USA). Illustrations, displayed in this manuscript referring to 3D polygonal data were edited in a 3D inspection software (GOM Inspect, Version 2018, Rev. 111035, GOM GmbH, Braunschweig, Germany). During the editing process, outer boundaries of the mesh were cleaned and parts of the mesh that held no additional and useful information, such as the table surface area of the autopsy table, were deleted.

Results

VirtoScan-on-Rails was installed and put into operation in late February 2018 at the blinded (Fig 3.1). The system was used to compute textured 3D models based on 53 photogrammetric image sets taken from 31 forensic cases (male: n=22; female: n=9). Table 3.1 shows a detailed list of the captured image sets and the corresponding forensic cases. The photographic image data acquired by the VirtoScan-on-Rails could not be saved in a RAW image format and simultaneously transferred to the associated computer workstation. Image datasets were saved in a JPG (Joint Photographic Experts Group) format instead.

First test series

During the first test series, the image-capturing sequence acquired 130 overlapping photographic images at 13 image-capturing positions over a distance of 1950 mm. The step-by-step movement of the image-capturing sequence was composed of 150-mm movements with a speed of 200 mm/s and subsequent breaks with a 2.3 s holdup. These breaks contain a 1 s stabilization phase to eliminate negative effects of camera vibration due to deceleration. The rest of the time is used to cover image acquisition and exposure time. Image-capturing sequences for autopsy tables 1 and 2 were set up identically and resulted in a scanning time of 1 minute each. The duration for the parking and un-parking of the system differed for the starting position of each table. In case of the first autopsy table, the duration for parking and un-parking totaled 28 s. Due to a longer traverse path, the duration for parking and un-parking of the second autopsy table accounted for 1 min and 12 s. The time duration for the full program to un-park, scan and park the system accounted for 1 min and 28 s in the case of table 1 and 2 min and 12 s for table 2. An overview of the distances and the corresponding time durations are given in table 3.2.

Seventeen forensic cases with 29 photogrammetric image sets were documented during the first test series. These forensic cases were split into 27 image sets taken during external examinations and 2 image sets taken during internal examinations. All image sets were successfully reconstructed with the help of Agisoft PhotoScan Professional Edition. The average computation time for the 3D reconstruction of textured 3D models with an average of 7 770 669 faces accounted for 3 h, 20 min and 55 s (Table 3.3). Textures of the computed 3D models showed blurred patches with indistinct differentiation of detail (Fig 3.2). The size and number of those patches varied across the 3D models. To some extent, the computed 3D meshes displayed rough-textured and noisy surfaces (Fig 3.3). In addition to this display, a pattern regarding the distribution of vertices was visible in the point cloud visualization of the 3D model. Along the body, repeating bands of dense and sparse vertices occurred across all datasets (Fig 3.4).

Second test series

In the second test series, 200 overlapping photographic images were acquired over a distance of 2000 mm. The step-by-step procedure was composed of 20 image-capturing positions and 100-mm movements. The starting positions for autopsy tables 1 and 2 were kept the same as in test series one, but seven additional image capturing positions were added at the end of the image-capturing sequence. Settings regarding velocity and holdup time were maintained from test series one. Image-capturing sequences were set identically for both autopsy tables and resulted in a scanning time of 1 min and 23 s for each table. To un-park, scan and park the system (complete imaging sequence), it took 1 min and 51 s in the case of table 1 and 2 min and 35 s for table 2. Detailed information about the distances and the corresponding time durations can be found in table 3.4.

During the second test series, 24 photogrammetric image sets out of 14 forensic cases were taken. Twenty-two sets of images were acquired during external examinations, and 2 sets of images were taken during internal examinations. Textured 3D models with an average of 10 049 395 faces were successfully reconstructed at an average computation time of 10 h, 2 min and 26 s (Table 3.3). Examples are provided in figures 3.5 to 3.8. Figure 3.5 shows a reconstructed 3D model of a dressed body. Figure 3.6 illustrates an undressed body during an external examination. The following two figures (Fig 3.7 and Fig 3.8) represent forensic cases of internal examinations. Figure 3.7 shows a 3D model of a body during an autopsy procedure, while figure 3.8 refers to a 3D model of an organ display. Textures of the computed 3D models did not exhibit any noticeable blurring artifacts across the models (Fig 3.2). Additionally, the surface of the 3D meshes featured smooth and less noisy surfaces compared to the computed models from test series one. Figure 3.2 illustrates the quality differences in the textured 3D models acquired during the first (images a and c) and the second test series (images b and d). Images a to c represent different forensic cases of a gunshot wound on the chest, whereas image d refers to a stabbing wound on the chest. Figure 3.3 compares the quality differences and the level of detail in the reconstructed meshes from different forensic cases acquired during the first (images a and c) and the second test series (images b and d). Patterns in the point cloud visualization were not visible in the 3D dataset from the second test run. The distribution of the vertices appeared to be more homogenous than in test series one. A comparison of the point cloud visualization between the first (images a and c) and the second test series (images b and d) is given in figure 3.3.

Discussion

This study presents a new 3D imaging system for automated whole-body 3D surface documentation at autopsy tables during different stages of external and internal examinations. Data quality, acquisition time and applicability of the system were evaluated within two test series. Based on the results of this study, the VirtoScan-on-Rails was found to be a fast and practical solution for whole-body 3D imaging in autopsy suites.

First test series

During the first test series, parameters for the image-capturing sequence were set up to attain an acquisition time of 1 min. With these settings, all image sets acquired during external and internal examinations were successfully reconstructed. However, the 150-mm distances between the image-capturing positions were shown to have negative effects on the quality of the 3D reconstruction. Patterns regarding the distribution of vertices were visible in the point cloud visualization. Bands of sparsely and densely distributed vertices appeared on the bodies of all forensic cases. A comparison of the image overlap with the point cloud visualization showed that areas with a sparse distribution of vertices were represented by only one set of consecutive images. Areas with a dense distribution of vertices, however, shared the overlap of two consecutive sets of images. Hence, bands with a sparse distribution of vertices lacked image information due to an insufficient overlap between the consecutive sets of images. Because of this difficulty, the distances between the image-capturing positions had to be decreased to achieve a higher quality in the 3D data.

Dust contamination occurred on the camera lenses when the VirtoScan-on-Rails was not in use. This contamination is why lens caps were manually removed and attached to the cameras before and after using the system. This procedure, however, made it difficult to maintain the focus settings on the cameras. Every time lens caps were removed or attached to the lenses, the camera focus was unintentionally altered to some extent. Ultimately, a subset of the images from the whole-body documentation featured photos that were slightly out of focus. As expected, this alteration negatively influenced the quality of the reconstructed 3D data. Textures were constructed based on a set of sharp and blurry images, which resulted in a blended texture with patches of indistinct differentiation of detail. In addition to that textural issue, the quality of the reconstructed 3D meshes appeared to have a noisy and unsmooth surface. This issue is possibly due to a combination of blurry images and the gap between the consecutive sets of images.

Second test series

The parameters for the image-capturing sequence were adjusted according to the results from the first test series. As expected, all image sets from the second test series were reconstructed successfully. The shorter distances between the image-capturing positions helped to remove the unequal distribution of vertices in the reconstructed data. A comparison of the image overlap with the point cloud visualization showed a homogenous overlap of two consecutive image sets across the whole body in all of the cases. Hence, a uniform distribution of vertices was visible in the point cloud visualization of the reconstructed 3D data.

All cameras were equipped with lens filters to prevent dust contamination on the lenses and to avoid the use of lens caps. In the case of increased dust contamination, air pressure was used to clean the filter surface. In addition to these actions, measures to mechanically fixate the focus rings on each camera lens were taken to secure the focus settings. These adjustments helped to reduce the appearance of blurry images. However, after performing a few imaging sequences, some of the cameras lost focus. It is possible that the motion of the image-capturing unit causes vibrations that may alter the camera focus. Therefore, image quality was inspected during every image-capturing process. In cases where cameras were out of focus, the image acquisition was stopped, and the focus was readjusted. This technique is why blurry patches did not occur during the second test series. Furthermore, compared to the results of test series one, the quality of the reconstructed 3D meshes appeared to have smoother surfaces with a slightly higher level of detail.

General remarks and applications

Based on the results of this study, VirtoScan-on-Rails demonstrated its potential to quickly acquire photogrammetric image sets at autopsy tables during different stages of external and internal examinations. VirtoScan-on-Rails enables the rapid acquisition of 3D whole-body surface documentation during routine work in autopsy suites. The automated and user-friendly workflow allows forensic pathologists or morgue technicians with a basic knowledge of photography to perform post-mortem 3D imaging. The automation not only facilitates the 3D imaging workflow but also allows for standardizing the photo documentation procedure. The use of a consistent camera setup with predefined settings, camera positions and angles allows for the standardization of image quality and the process of image acquisition during a photographic documentation. However, even though the photogrammetric image sets cover one whole side of the body, additional photographs might be needed to meet the requirements of a photographic documentation. Usually, several regions on the body are occluded and are difficult to capture with an automated setup. These regions (e.g., fingers, toes, inner side of the lower and upper extremities, axillas, auricles, eyes, mouth, genitalia, anus, etc.) usually require individual and detailed photographs.

Nevertheless, VirtoScan-on-Rails makes 3D surface documentation more applicable to forensic investigations. Furthermore, it contributes to using 3D data to more commonly reconstruct the sequence of events. Fast acquisition times and automated imaging procedures lower the overall costs for investigations involving 3D documentation and analysis. Compared to alternative 3D surface imaging techniques, the ability to use individual images from the photogrammetric data as supporting and reliable evidence in addition to the reconstructed 3D model can be considered advantageous for forensic investigations. Consequently, this technology makes 3D surface documentation more appealing for legal authorities. Integrating the VirtoScan-on-Rails into routine work would provide standardized, high-quality photo documentation with 3D interactive content to the legal authorities. The use of the VirtoScan-on-Rails may not be restricted only to the documentation of bodies but may in some cases contribute to the 3D documentation of objects, weapons and materials that are relevant to the case. Apart from expert reports and photo documentation in line with legal investigations, the VirtoScan-on-Rails can be used to acquire 3D data for educational purposes. 3D imaging could be used to document workflows in line with forensic examinations such as autopsy procedures. Furthermore, it could be used to collect 3D image data to prepare an interactive 3D encyclopedia of human anatomy and pathology.

Future improvements

Based on the results of this study, future advancements could be made to improve image and 3D data quality as well as the data acquisition time duration of the image-capturing process. Enhancements regarding these topics may be achieved by upgrading the camera setup using higher quality cameras and lenses. Due to budget restraints the VirtoScan-on-Rails was chosen to comprise a set of DSLR cameras and camera lenses of a low price range. The Canon EOS 100D DSLR camera model was released in early 2013 and hence does not represent the latest advancements made in this sector. Replacing the camera setup on the VirtoScan-on-Rails with a set of newer and higher quality cameras and lenses will improve image quality and ultimately contribute to a higher level of detail in the reconstructed 3D data. Furthermore, higher quality camera lenses might help to overcome the focus issues identified in this manuscript and might enabled making use of the auto-focus feature. This would allow the system to automatically adjust for subjects of varying size.

Adding an improved lighting system to the VirtoScan-on-Rails could improve the quality of the data output and contribute to the operational procedure of the system. The primary light source in the autopsy room is currently angled orthogonal to the table area of each autopsy table. Hence, bodies that are placed on autopsy tables are not uniformly lit. Shadowing effects commonly appear on body regions that are in close proximity to the table surface area of the autopsy tables (e.g., inner and outer side of the lower and upper extremities). A dedicated lighting system could help to uniformly distribute the light across the bodies at autopsy tables. This distribution could improve the overall image quality and decrease the exposure time, consequently reducing the acquisition time of the image-capturing process.

Body regions that are perpendicular to the axial plane are currently captured with less accuracy than other regions of the body. To cover the body surface in more detail, further cameras with supplementary camera angles could help to resolve this issue. During test series one and two, bodies with large dimensions have exceeded the boundaries of the field of view that is currently captured with the VirtoScan-on-Rails. Thus, the reconstructed 3D data exhibited incomplete models that usually missed 3D information regarding the upper and, to some extent, the lower extremities. Substituting the current set of camera lenses with a wide-angle alternative could help enlarge the field of view and consequently overcomes this limitation.

Finally, the quality of the 3D data could be enhanced by using a RAW image format for image registration and reconstruction instead of compressed JPG files. The current data transfer speed does not allow the simultaneous capture of photos in a RAW image format while transferring them to the associated computer workstation. An update regarding the data transfer architecture could yield faster transfer rates and allow the use of RAW image formats for the 3D reconstruction.

Conclusion

VirtoScan-on-Rails is an automated, fast and easy-to-use 3D imaging setup that facilitates documenting bodies during different stages of forensic examinations. This technology contributes to the routine work in autopsy suites and allows the standardization of the procedure of photo documentation.

Compliance with ethical standards

Funding

This work was funded by the Investment Fund of the University of blinded

Conflict of Interest

The authors declare that co-authors of this manuscript are affiliated with the organization, which was assigned to develop, build and install the VirtoScan-on-Rails. This organization may be affected by the research reported in the enclosed paper and may have financial interests to commercialize VirtoScan-on-Rails systems in the future.

Ethical approval

The 3D datasets of humans were acquired as part of forensic judicial investigations. Anonymized results of these datasets are used in this publication. This data usage is conformant with laws and ethical standards as approved by the Ethics Committee (written approval, blinded).

Informed Consent

Informed consent was obtained from all individual participants included in the study.

Figures and Tables

Figures

Fig 2.1 Floor plans of the autopsy facilities at the blinded. Overview of the whole autopsy facility (a) and a detailed view of autopsy room 1 (b).

Fig 2.2 Main sequences of the image-capturing process: unparking (a), image acquisition (b) and parking (c).

Fig 3.1 VirtoScan-on-Rails at the starting position of autopsy table 1.

Fig 3.2 Comparison of the texture quality in the reconstructed 3D data from test series one (images a and c) and two (images b and d). Images a to c compare the texture quality of a gun-shot wound from different forensic cases, whereas image d refers to a stabbing wound.

Fig 3.3 Comparison of the level of detail in the reconstructed 3D data from test series one (images a and c) and two (images b and d). Images a to d compare the level of detail in the 3D mesh from different forensic cases. Images a and b illustrate detailed views of two different forensic cases in prone position. Images c and d refer to detailed views of two different forensic cases in supine position.

Fig 3.4 Distribution of vertices in the point cloud visualization of the reconstructed 3D data. Comparison between four different forensic cases from test series one (images a and c) and test series two (images b and d).

Fig 3.5 Reconstructed 3D model of a dressed body during an external examination. 3D reconstruction is based on photogrammetric image data acquired by the VirtoScan-on-Rails. Image a illustrates the 3D mesh of the reconstructed data, whereas image b refers to the corresponding view of the textured 3D model.

Fig 3.6 Reconstructed 3D model of an undressed body during an external examination. 3D reconstruction is based on photogrammetric image data acquired by the VirtoScan-on-Rails. Image a illustrates the 3D mesh of the reconstructed data, whereas image b refers to the corresponding view of the textured 3D model.

Fig 3.7 Reconstructed 3D model of a body during an autopsy procedure. 3D reconstruction is based on photogrammetric image data acquired by the VirtoScan-on-Rails. Image a illustrates the 3D mesh of the reconstructed data, whereas image b refers to the corresponding view of the textured 3D model.

Fig 3.8 Reconstructed 3D model of an organ display during an internal examination. 3D reconstruction is based on photogrammetric image data acquired by the VirtoScan-on-Rails. Image a illustrates the 3D mesh of the reconstructed data, whereas image b refers to the corresponding view of the textured 3D model.

Tables

Table 2.1 Overview of the camera settings used with the VirtoScan-on-Rails during test series one and two.

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Table 3.3 List of measurements reflecting data size, level of detail and computation time for test series one and test series two.

Table 3.4 Distances and corresponding time durations for the different sequences and traverse path of the image-capturing unit (ICU) during the second test series. The image-capturing sequence was composed of 20 image-capturing positions with 100-mm movements over a distance of 2000 mm.

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32. blinded

33. blinded

Figure 2.1

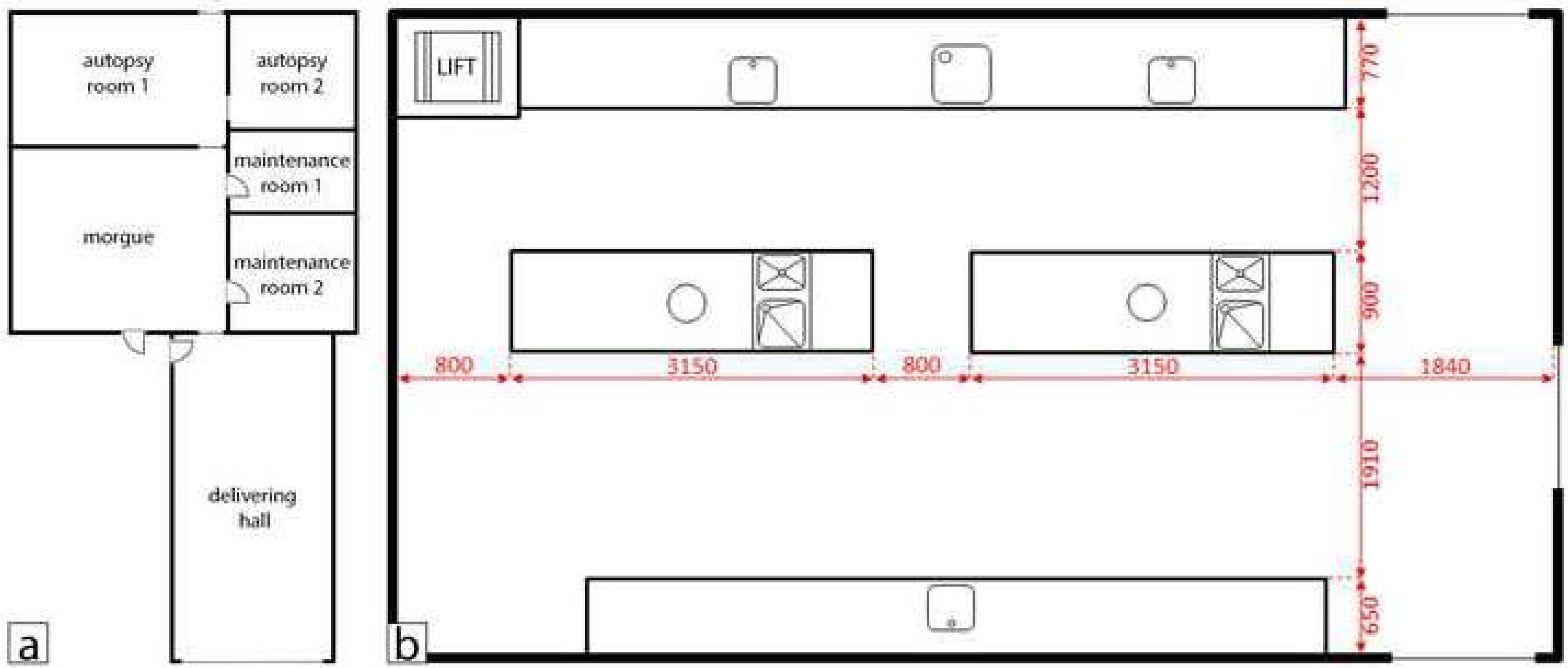

autopsy room 1
autopsy room 2
maintenance room 1
morgue
maintenance room 2
delivering hall
a
LIFT
770
1200
900
800
3150
800
3150
1840
1910
650
b

Figure 3.1

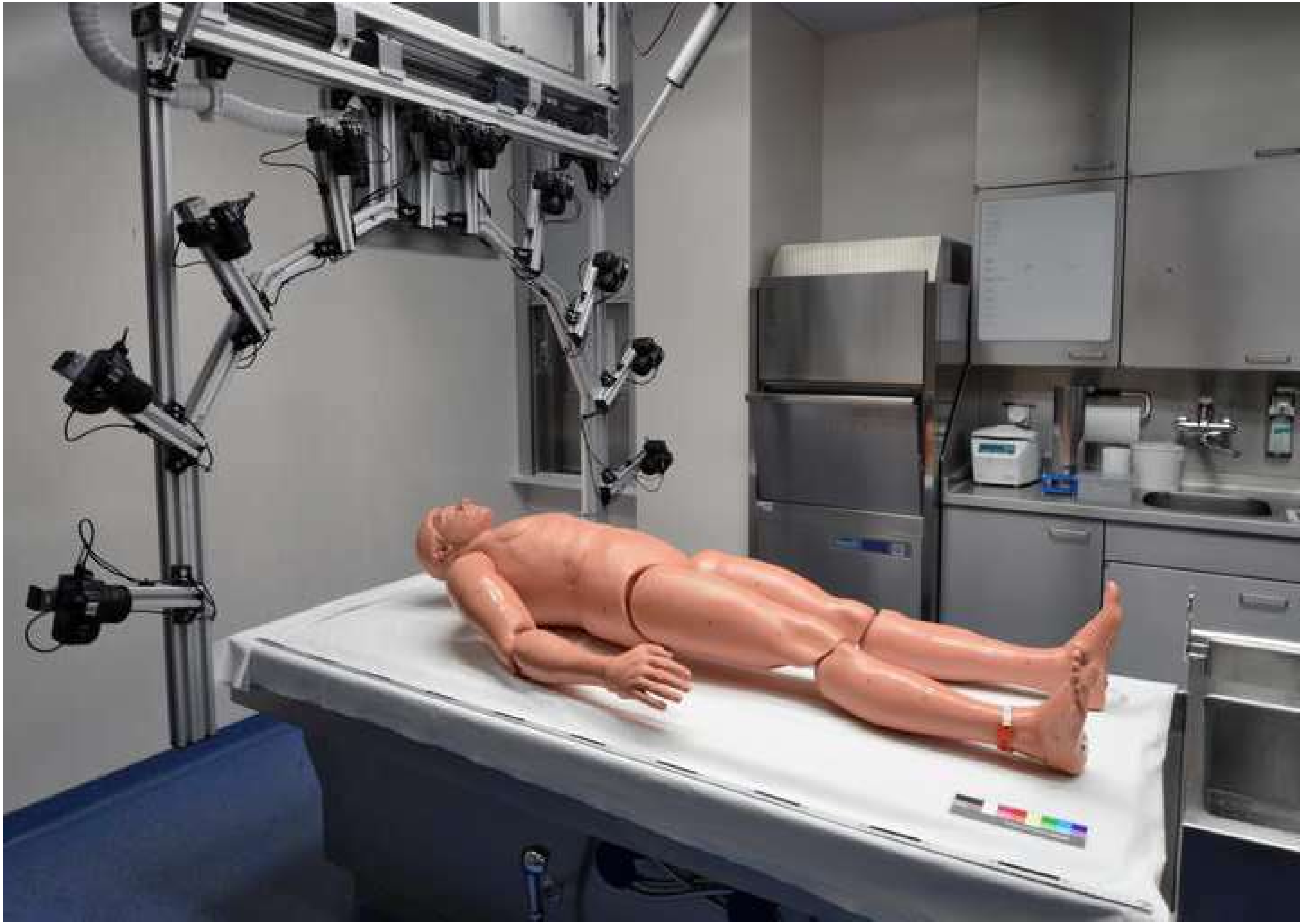


Figure 3.2

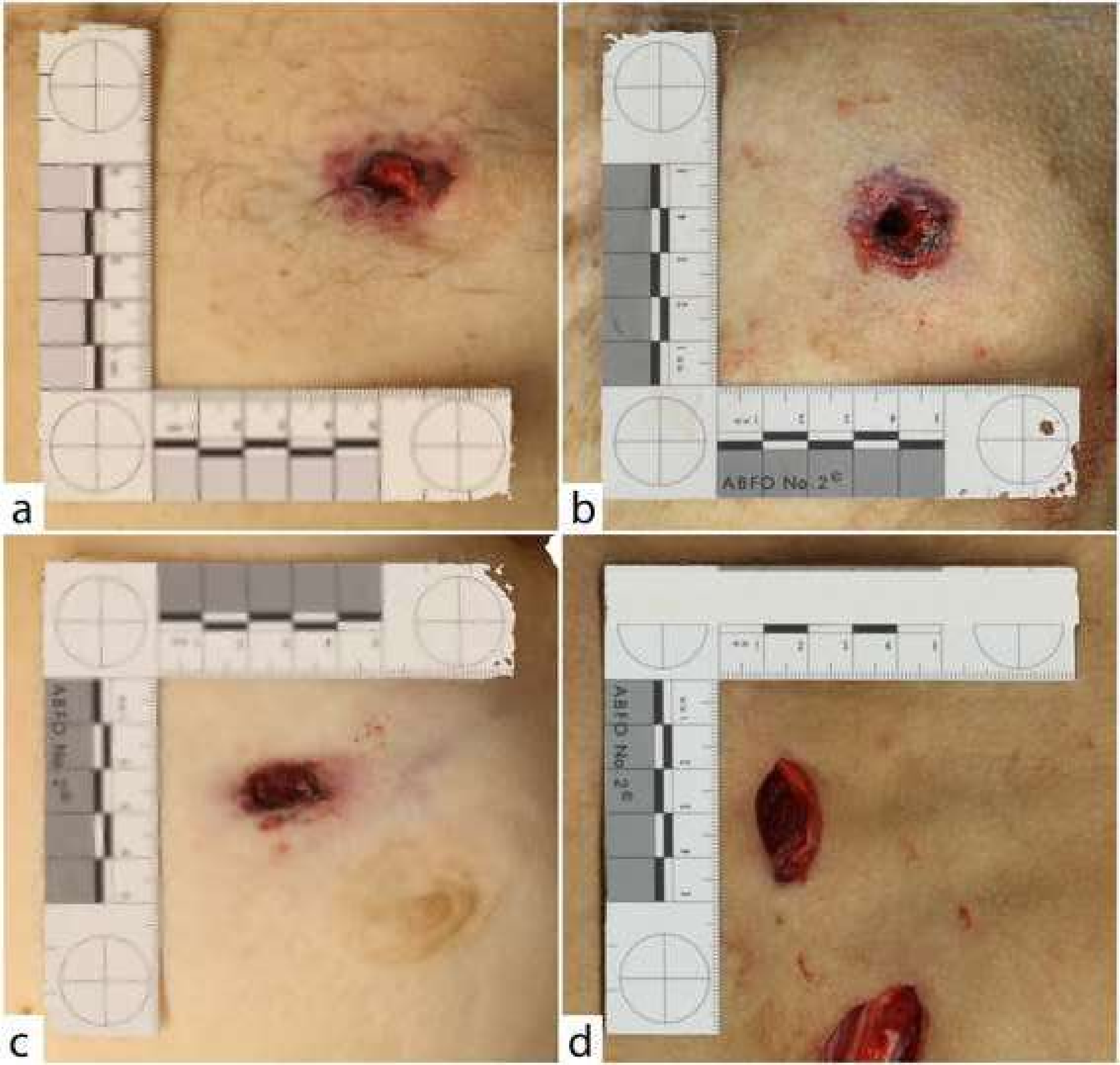


Figure 3.3

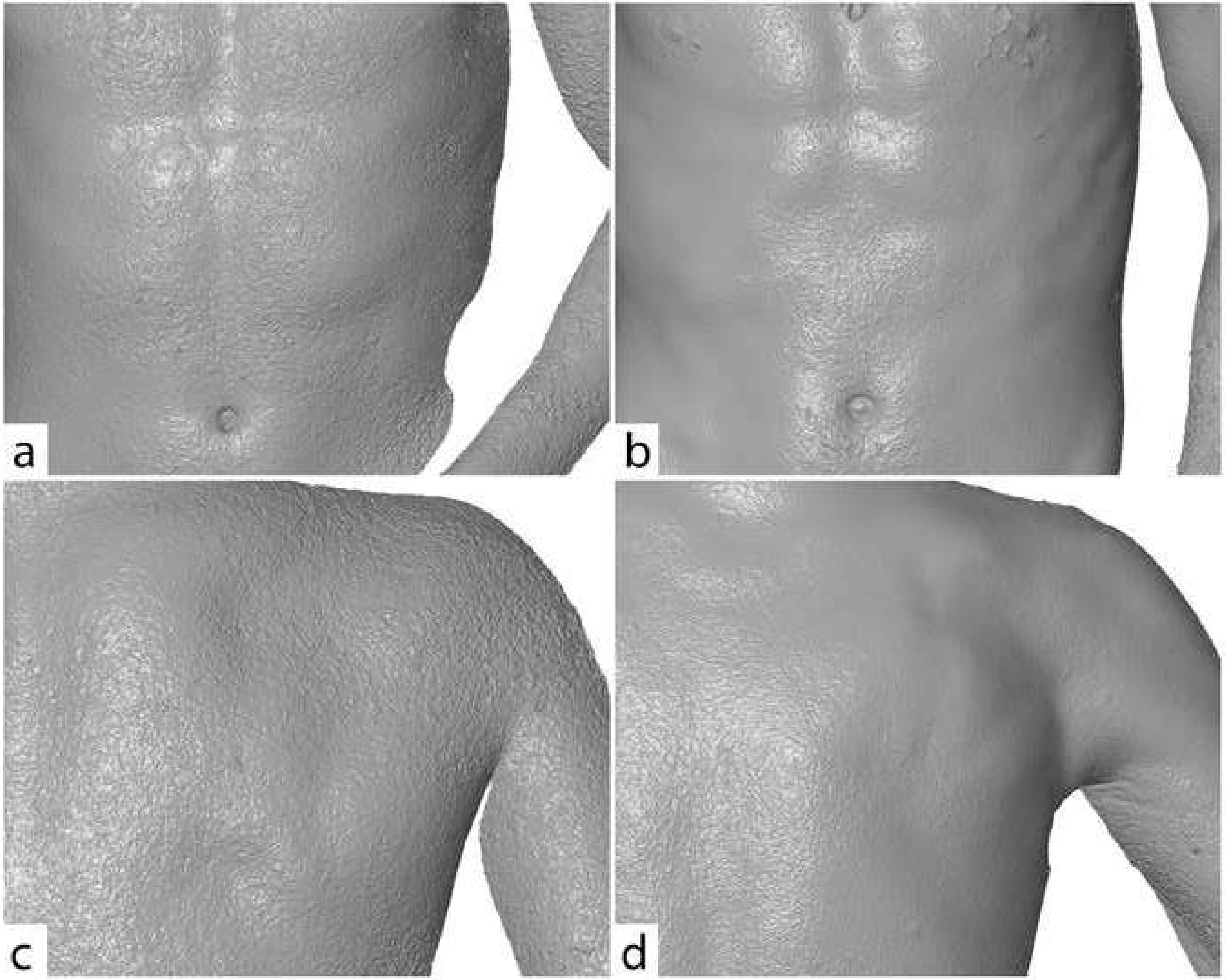


Figure 3.4

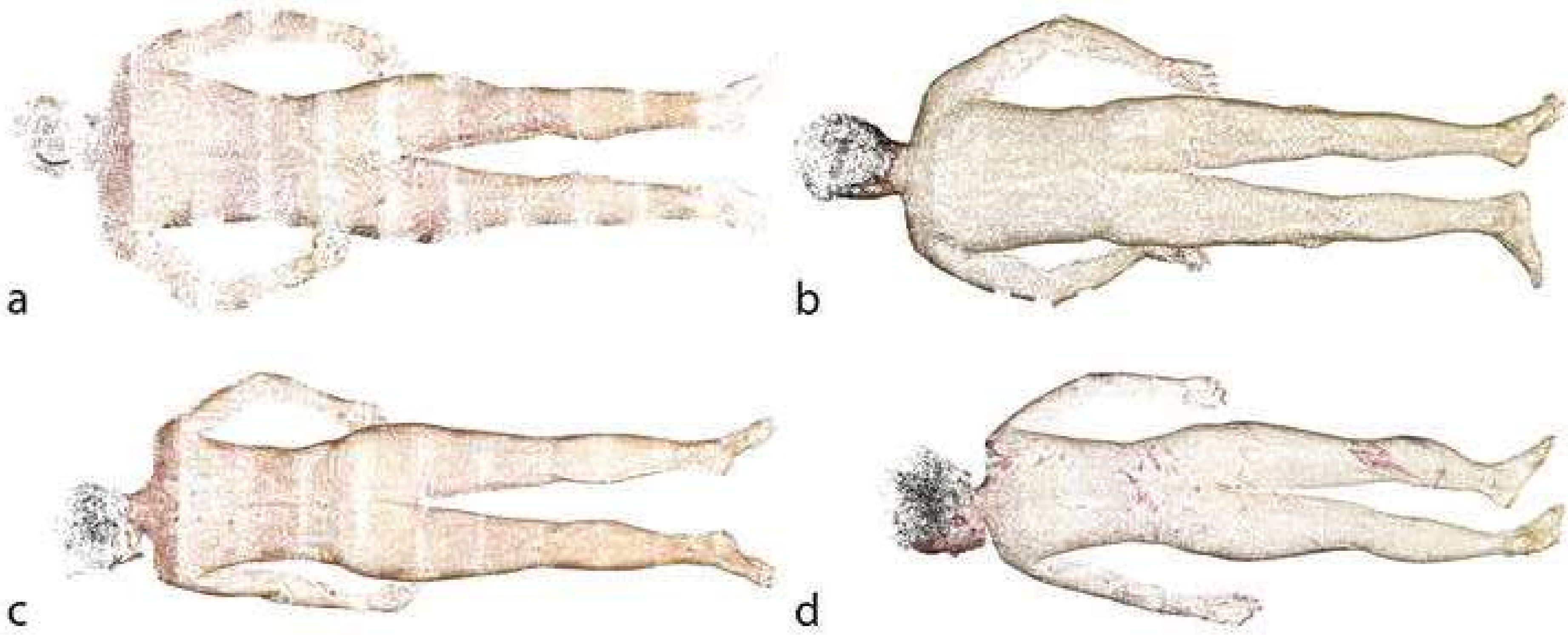
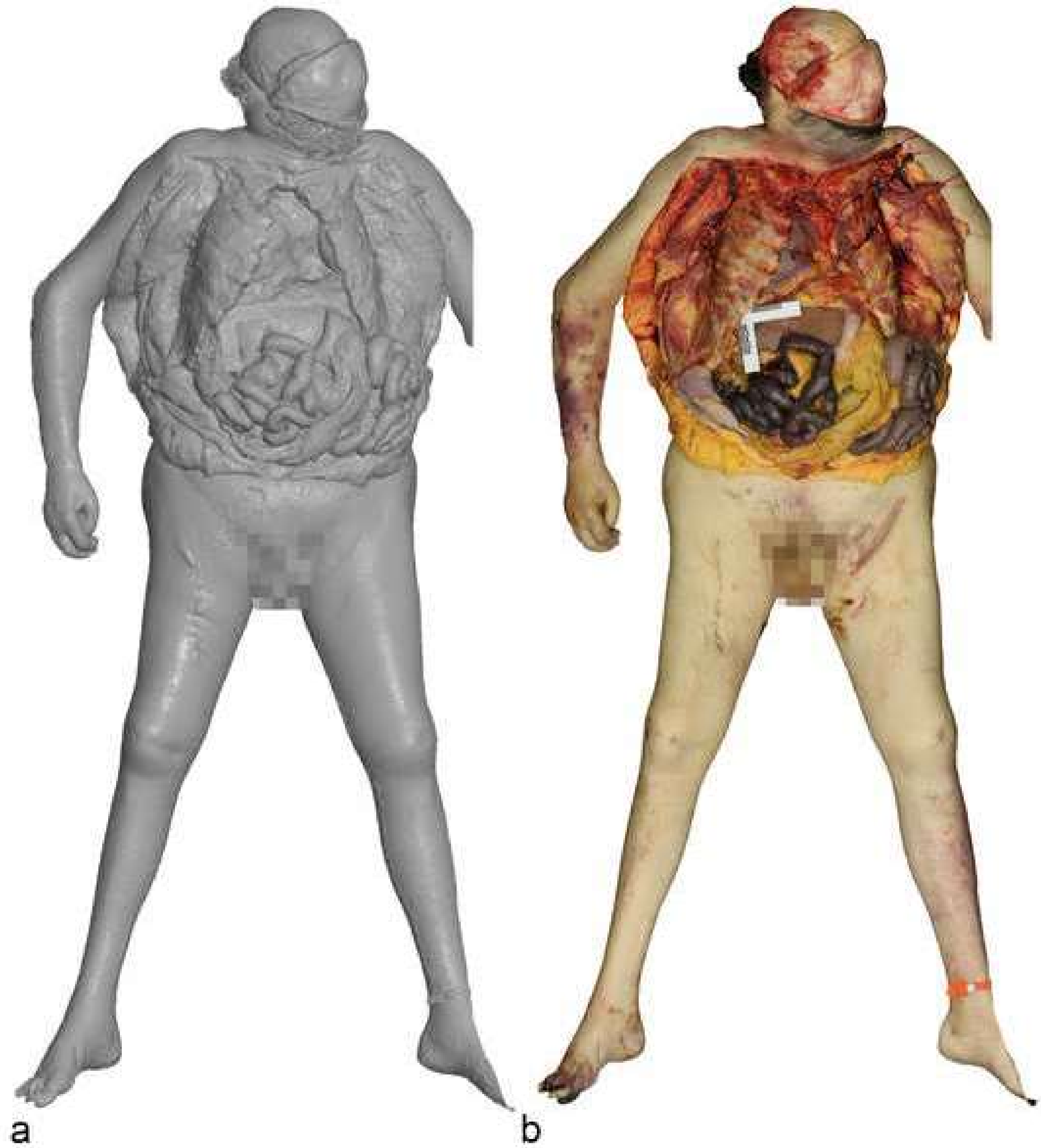


Figure 3.5

a b

Figure 3.6

Figure 3.7



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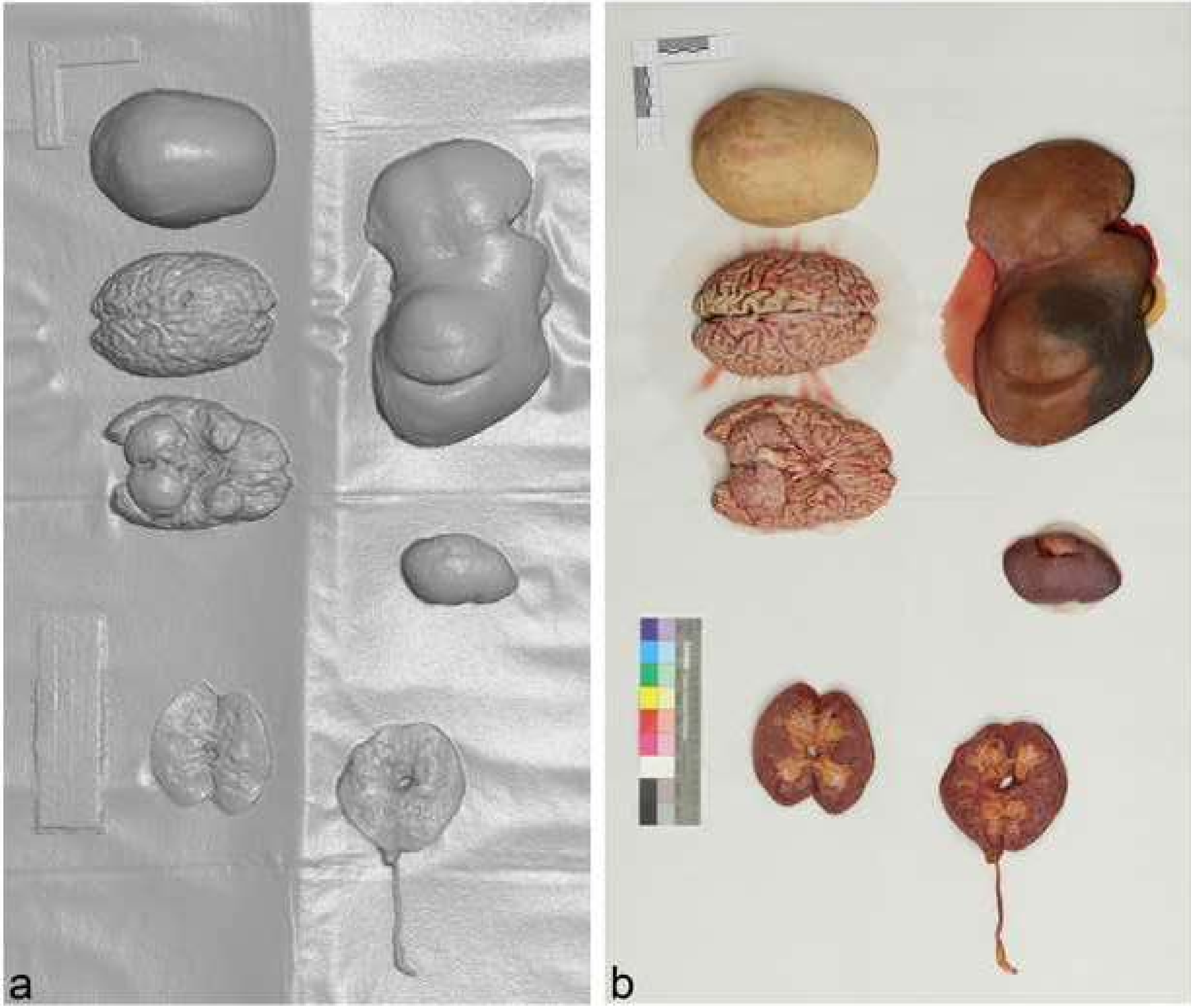

Figure 2.2

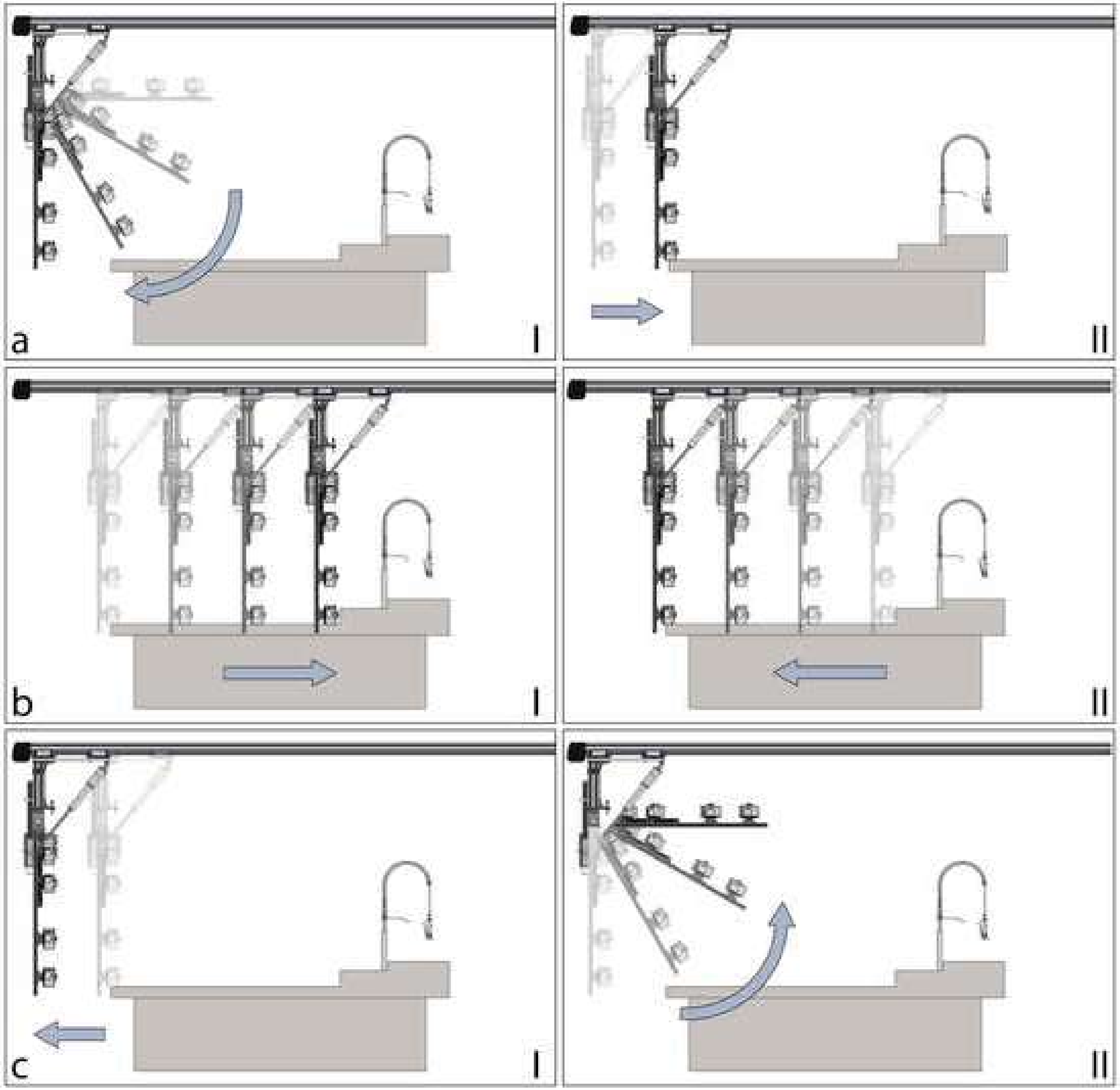

Table 2.1

parameter	value / setting
iso-value	100
aperture	f/22
exposure time	1/3s
white balance	4000 Kelvin
file type	JPG
camera focus	manual mode

Table 3.1

test series	cases	female	male	scans	external examinations	internal examinations
series one	17	4	13	29	27	2
series two	14	5	9	24	22	2
both	31	9	22	53	49	4

Table 3.2

traverse paths of the ICU	**duration [mm:ss]**	**distance [mm]**	**velocity [mm/s]**	**acceleration ramp [mm/s^2]**
unpark to table 1 1)	0:14	400	200	300
unpark to table 2 1)	0:36	4680	200	300
park from table 1 1)	0:14	400	200	300
park from table 2 1)	0:36	4680	200	300
scan at table 1 2)	1:00	3900	200	300
scan at table 2 2)	1:00	3900	200	300
movement between tables 1 & 2	0:22	4280	200	300
complete program for table 1 1),2)	1:28	4700	200	300
complete program for table 2 1),2)	2:12	13260	200	300

1) Time duration for raising or lowering the ICU accounts for 12 sec

2) Step-by-step movement includes a 2.3-sec holdup

Table 3.3

measurements	**test series one**	**test series two**
number of photos	130	200
data size of photos [GiB]	0.54	0.88
data size of agisoft file [GiB]	1.31	1.76
number of vertices	3 895 779	5 035 710
number of faces	7 770 669	10 049 395
computation time [hh:ss:mm]	3:20:55 AM	10:02:26